Cosmological Constraints on Dynamical Dark Matter

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May 5, 2015

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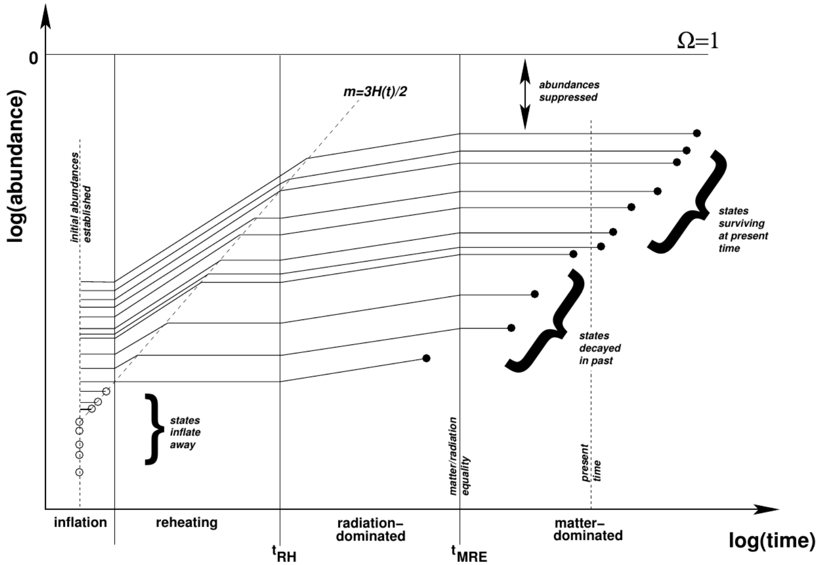
Multicomponent decaying DM that balances Γ_X and Ω_X



Apply decaying DM constraints to a DDM ensemble

Decay Channel	$\tau_X \lesssim t_{now}$	$\tau_X \gtrsim t_{now}$
Electromagnetic (Photons)	BBN (μ + y_C)	Ionization (Diffuse)
Hadronic	BBN	Ionization, AMS p^-
Neutrinos	CνB Scattering	IceCube Diffuse
Invisible	Density at t_{MRE}	Relic Density

Parametrizing the DDM ensemble

$\Gamma_i = \Gamma_0 \left(m_i/m_0\right)^\gamma$ $\Omega_i = \Omega_0 \left(m_i/m_0\right)^\alpha$

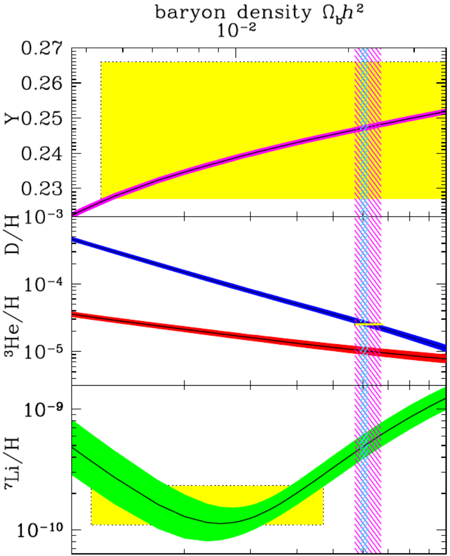
$m_i = m_0 + n^\delta \Delta m \quad \gamma, \delta > 0 \quad \alpha < 0$

- Normalize Ω_0 to get relic density from components with $\tau_i > t_{now}$
- Assume $m_0 = \Delta m \sim 0.1\,\mathrm{keV}$ for simplicity and phenomenology
- Motivated by models with "dark tower" of unstable KK modes

This talk assumes decays $\to \gamma\gamma$

- Decays during early universe necessarily from heavier components in ensemble, set $\tau_0 \sim t_{now}$, $\delta = 1.5$ for BBN
- Decays today require hyperstability of most abundant components, set $\tau_0 \gg t_{now}$, $\delta = 3.0$

EM injection in the early universe can ruin BBN



Degraded photon spectra

- Decay photons cooled by
  $\gamma + \gamma_{BG} \to e^+ + e^-$,
  $e^\pm + \gamma_{BG} \to e^\pm + \gamma$
- Will remain in quasistatic equilibrium until thermalization

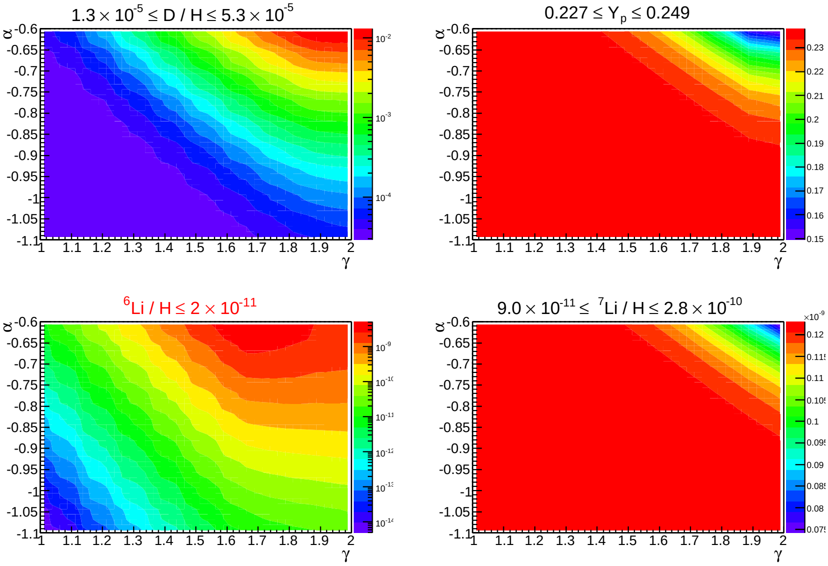
Photodisintegration $i(\gamma, j)k$

$$\delta Y_i \sim -N_\gamma Y_X Y_i \frac{\sigma_{i(\gamma,j)k}}{\sigma_{therm}}$$

Primary: $^4\mathrm{He}(\gamma, d)d$, $d(\gamma, n)p$, $^7\mathrm{Li}(\gamma, n)^6\mathrm{Li}$, $^6\mathrm{Li}(\gamma, np)^4\mathrm{He}$, $^4\mathrm{He}(\gamma, n)^3\mathrm{He}$, $^4\mathrm{He}(\gamma, p)t$

Nuclear: $^4\mathrm{He}(^3\mathrm{He}, p)^6\mathrm{Li}$, $^4\mathrm{He}(t, n)^6\mathrm{Li}$

$m_i = m_0 + n^\delta \Delta m \ , \Omega_i = \Omega_0 \left(m_i / m_0 \right)^{\alpha} \ , \tau_i = \tau_0 \left(m_i / m_0 \right)^{-\gamma}$



EM injection at recombination can ionize the CMB

Expands last scattering surface

- Photon cooling processes similar to EM cascades which alter abundances
- Photons that cool on time scales $\sim t_H$ ionize HI
- Constrains injection rate at recombination from components with $\tau_i \gg t_{now}$

Limits total instantaneous rate

$$\sum_i \Omega_i \Gamma_i \lesssim 3 \times 10^{-26}\,\mathrm{s}^{-1}$$

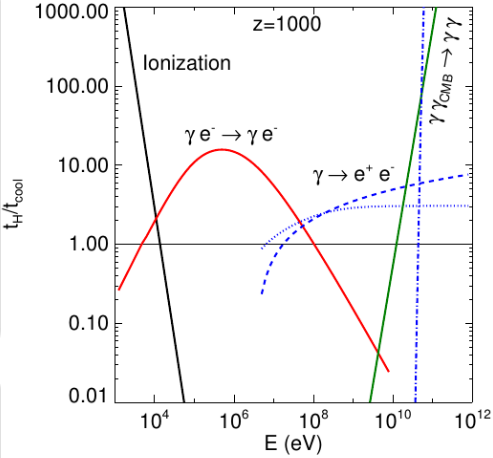
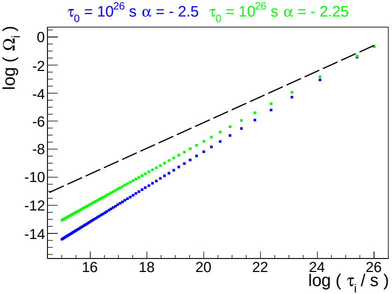
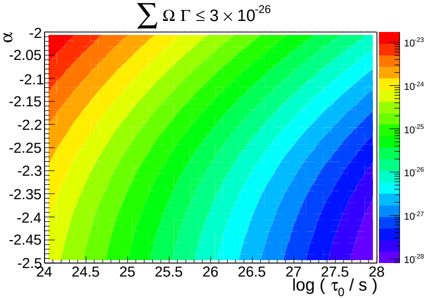


Figure: From 0906.1197, shows time scales for cooling processes as a function of E_γ.

$m_i = m_0 + n^\delta \Delta m$, $\Omega_i = \Omega_0 \left(m_i / m_0 \right)^\alpha$, $\tau_i = \tau_0 \left(m_i / m_0 \right)^{-\gamma}$





- Less sensitive to less abundant earlier decaying components, fix $\gamma = 2$
- Left plot shows two ensemble model points and limits from 1211.0283
- Decreasing α reduces to single component limits requiring $\tau_0 \gtrsim 10^{26}\,\mathrm{s}$
- More dynamical with increasing α, faster injection with decreasing τ_0

Photons from decays $\sim t_{now}$ contribute to diffuse flux

Boltzmann eqn for each component

$$\dot{n}_\gamma + 3Hn_\gamma = 2\sum_i \Gamma_i \frac{\rho_i}{m_i}$$

$$\frac{dn_\gamma}{dE_\gamma} \sim 6\rho_{c,0} \sum_i \frac{t_{now}}{\tau_i} \frac{\Omega_i}{m_i^2}$$

- Limits instantaneous injection rate today given $\tau_i \gg t_{now}$
- Each component puts flux into a different "bin" with $E_\gamma \sim m_i/2$
- Components do not contribute coherently to the spectrum

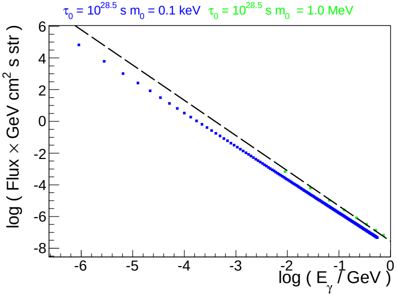
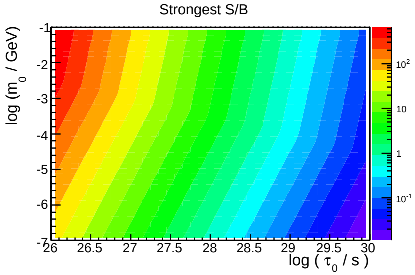
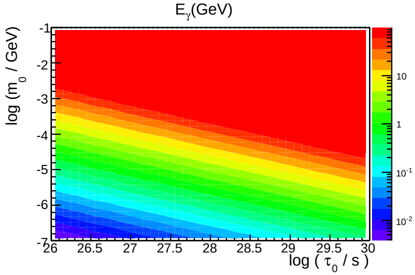


Figure: Diffuse photon flux contributions from dynamical ensembles with $\alpha = -2.1$ and $\gamma = 2$. Dashed line is an approximate combination of power laws for the limits described in 1203.1923 .

$m_i = m_0 + n^\delta \Delta m$, $\Omega_i = \Omega_0 (m_i/m_0)^\alpha$, $\tau_i = \tau_0 (m_i/m_0)^{-\gamma}$





- Left plot shows the largest ratio of excess flux over observed limits
- Right plot shows the observed E_γ corresponding to largest excess
- $E_\gamma \gg m_0$ suggests departure from single component limits
- Heavier less abundant components subject to more stringent limits

Summary and Outlook

- DDM provides for application of decaying DM constraints to multicomponent scenarios
- Light elements can constrain short lived and less abundant DDM ensemble components
- CMB and the diffuse photon flux constrain complementary pieces of hyperstable ensembles
- Alter CMB with decays before recombination and consider additional indirect constraints
- Calculate with nonuniform decays and redshift dependence
- Include finite detector resolution
- Consider other decay channels, alterations to cosmological timeline and structure formation

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Thank you!


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